# RETROSPECTIVE ANALYSIS OF REGIONAL CLIMATE: THE GERMAN REANALYSIS PROJECT - POTENTIAL OF REMOTE SENSING OBSERVATIONS.

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## ABSTRACT

This contribution presents an overview and first results of the recently started German Reanalysis Project. The overall vision of the project is to develop a self-consistent assessment and analysis of regional climate in Germany and Central Europe over the past decades using the operational NWP model COSMO from the German Weather Service (DWD). An important part of the project includes the extensive validation and quality control of the reanalysis product. Therefore, data from various ground-based observational networks are used as well as satellite observations. In order to compare the reanalysis output with microwave observations in the observational space, an active and passive microwave forward operator has been developed and applied to the first reanalysis test month. First results of an analysis with special focus on the influence of the latent heat nudging scheme on water cycle and cloud structure are presented.

***Index Terms—*** Regional Reanalysis, Atmospheric Remote Sensing, Latent Heat Nudging

## 1. INTRODUCTION

A precise, comprehensive, and self-consistent analysis of the past climate system state is a requirement for the detection and attribution of regional climate change and subsequent measures of mitigation and adaptation strategies. Due to the complexity of the climate system and vast differences in quality and availability between monitoring systems, the problem of providing a detailed picture of past climate variability, especially on comparably small regional scales, is far away from being solved. A homogeneous and highly resolved gridded data set is a prerequisite for a vast field of applications and research projects and hence a particular challenge facing the community at large. Retrospective analyses of the atmospheric state provide a valuable resource in climate research and applications. Over the past decade, a number of such retrospective analyses, i.e. reanalyses, have been created on a global basis e.g. NCEP-NCAR reanalysis dataset NNR (1948-present), the European Centre for Medium Range Weather Forecasting (ECMWF) Reanalyses ERA 40 (1957-2002) and ERA Interim (1989-present). In contrast to global products, regional reanalysis products with grid sizes < 30 km are comparably rare.

## 2. THE GERMAN REANALYSIS PROJECT

The German Reanalysis Project is the first phase (2011-2014) of the joint project Retrospective Analysis of Regional Climate[1] for use in Climate Change Analysis funded through the Hans-Ertel-Centre for Weather Research programme (HErZ). The overall vision of the project is to develop a self-consistent assessment and analysis of regional climate in Germany and Central Europe over the past decades at appropriate spatial and temporal resolutions. It encompasses the synergetic use and assimilation of heterogeneous monitoring networks, including historical station data and satellite data, to construct state-of-the-art regional reanalysis datasets for Germany and Central Europe and their evaluation. The regional reanalysis is based on the numerical weather prediction model COSMO with horizontal grid spacings of 7 and 2.8 km resolution, as it is in operational use at DWD. Two different versions of the reanalysis focus on the comparably short time frame of five years with the maximum amount of observation data and nested into ERA-interim, and the past decades with a reduced data basis, in order to aim at more homogeneous time series than typically available in long-term reanalyses. The reanalysis project will provide a quality-controlled and homogenised data set as a basis for the detection and assessment of regional climate change in past and future, for the statistical post-processing of operational forecasts, for the analysis of systematic model errors of the respective

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[1] http://www.herz-tb4.uni-bonn.de/

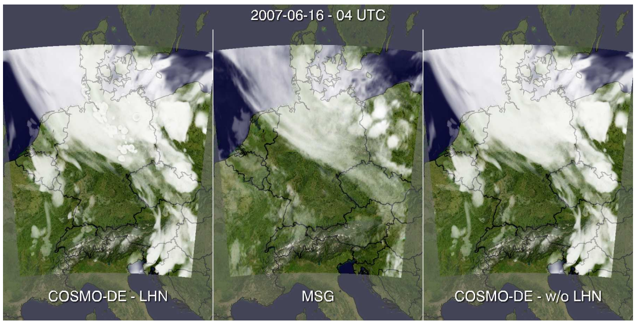

**Figure 1: Synthetic MSG-SEVIRI brightness temperatures for the 10.8 µm channel simulated using the RTTOV forward operator for 16th June 2007, 04 UTC based on COSMO-DE with LHN (left) and without LHN (right). The true MSG observation is shown in the middle.**

regional model, and for verification and calibration of impact models such as hydrological models.

## 3. VALIDATION AND QUALITY CONTROL

Synergetic evaluation of the reanalysis makes use of a multitude of independent, i.e. not assimilated data (rain gauges, radar, micro rain radar, ceilometer network, high-resolution radio soundings, GPS network for integrated water vapor) available by the General Observation Period (GOP) during 2007/08 [1]. In addition to those ground-based networks a major focus will lie on observations in the infrared made by the SEVIRI instrument on board the Meteosat Second Generation (MSG) satellite as well as microwave radiances provided by passive satellite sensors. The assimilation of microwave radiances as observed by polar orbiting satellites currently builds the back bone of operational data assimilation for global models. However, the information is generally limited to humidity and temperature in clear sky situations. Because microwave observations are also strongly affected by clouds and precipitation, the use of this information is highly desirable, but is complicated to incorporate as scattering at particles of different size and shape needs to be accounted for. Since passive satellite observations are not assimilated in the COSMO model they can be used as independent data for validation.

## 4. PASSIVE AND ACTIVE RADIATIVE TRANSFER OPERATOR PAMTRA

State of the art attempts to include precipitation information rely on a relatively simple treatment of scattering effects like those implemented in the fast Radiative Transfer model for TOVS (RTTOV) [2].

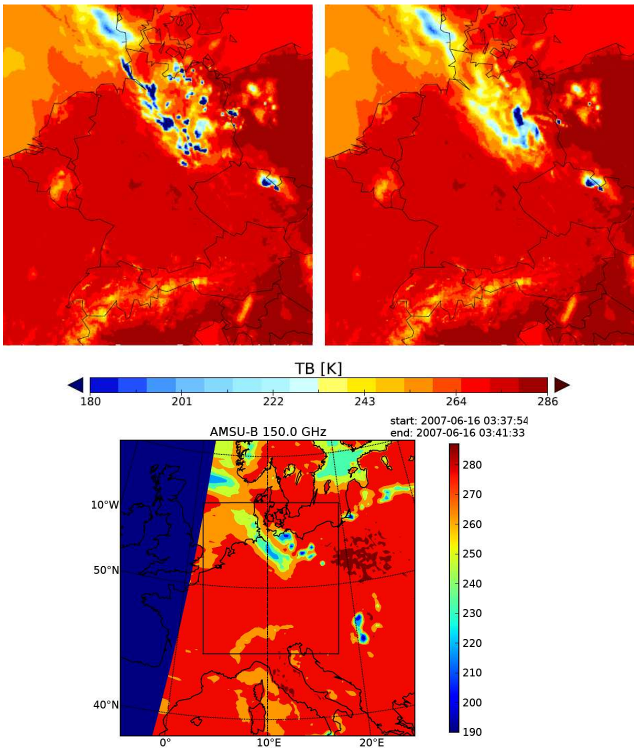

**Figure 2: Upper panel: PAMTRA simulations of passive microwave brightness temperatures (TB, color scale) at 150 GHz for a space-borne sensor. The reanalysis fields for the simulation are from 16th June 2007, 04 UTC with operational LHN (left) and without LHN (right). The actual AMSU observations at 03:40 UTC are shown in the lower image. Note that the simulations are based on the COSMO-DE model resolution and are not averaged onto the AMSU footprint.**

Comparisons of numerical weather prediction models coupled to an explicit radiative transfer model with observation from the Advanced Microwave Sounding Unit (AMSU) have shown encouraging results [3] and the superiority compared to RTTOV [4]. Within the reanalysis project a forward operator for passive and active microwave observations (PAMTRA) has been developed. PAMTRA extends the widely used RT3 model [5] by an active component in order to be able to simulate radar observations, e.g. cloud radar observations from the CloudSat satellite. PAMTRA is designed in a very modular way which allows for including the most recent scattering databases for frozen hydrometeors or different absorption models for super-cooled liquid water [6] [7]. The implemented ice/snow particle habits currently include spheres, spheroids as well as a number of realistic ice particles such as hexagonal plates, columns, rosettes or dendrites [8]. Additionally, particle size distributions of all hydrometeors can be explicitly defined which enables PAMTRA to run with microphysical assumptions consistent to the COSMO model microphysics used in the reanalysis. The implementation of various microphysical assumptions also allows for estimating the uncertainty which is introduced by the different assumptions. This is particularly important for the interpretation of the model-observation comparisons.

## 5. FIRST APPLICATION OF PAMTRA AND VALIDATION DATA TO REANALYSIS

In preparation of the five year short time reanalysis period several tests have been performed for the month June 2007 to ensure the proper configuration of the reanalysis system. The COSMO-DE model settings (2.8 km for Germany) include a latent heat nudging (LHN) scheme, which allows for assimilation of weather radar network data into the model to enhance the analysed precipitation fields. The LHN scheme forces the model to adjust the precipitation field according to the radar observations by changing locally the latent heat profile. The model has been run with different increments of LHN ranging from completely disabled LHN to the operational LHN scheme. Comparisons with independent rain gauge measurements exhibit a clear improvement of the predicted precipitation with LHN. The maximum RMSE for the test month over the entire model area decreased from 0.07 mm/h to 0.04 mm/h by turning the LHN on to the operational settings. Though, LHN seems to be beneficial on the precipitation field, it has considerable effect on the cloud field. Figure 1 shows an example of the synthetic satellite images generated by RTTOV using the COSMO-DE reanalysis for enabled/dis-abled LHN together with a true satellite image from MSG-SEVIRI. The overall structure of the clouds is well represented in COSMO-DE but too many high clouds are produced – which is consistent to former studies [9]. In the LHN case small scale cloud structures appear over north to north-east Germany. These structures represent local thunderstorms which are triggered by the LHN. They are artificially created and do not appear in the MSG image. While they have been found to disappear with increasing forecast time, these effects could lead to biases in the reanalysis product. More detailed studies revealed that a slight decrease of LHN (to 75%) can significantly reduce the number of local thunderclouds and their impact on the number of very high (cold) clouds while the improvements in the precipitation field are only slightly affected.

Similar studies on LHN have been performed applying PAMTRA to the reanalysis output and comparing the results to observations (Figure 2). In a cloud–free case a passive satellite sensor receives the thermal emission of the earth surface and the atmosphere. The received intensity is usually expressed as brightness temperature (TB). Clouds containing large ice particles and snow lead to lower TB (TB depression) due to scattering of the upwelling thermal emission out of the line-of-sight by the frozen hydrometeors.

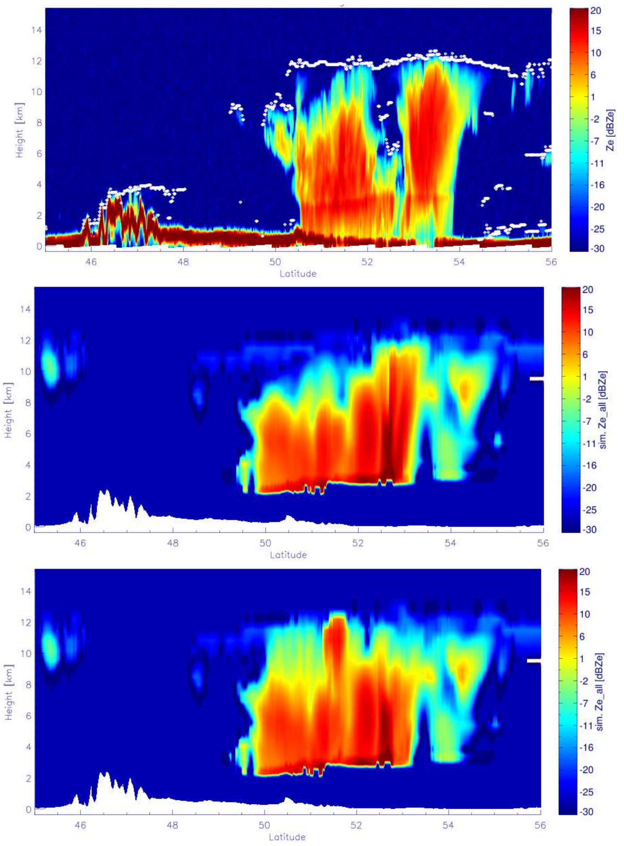

**Figure 3: Radar reflectivity profiles (Ze) at 94 GHz as function of latitude and height (km) for 16th June 2007 (00 UTC). Upper panel: CloudSat radar observations and collocated cloud top information from the space-borne lidar onboard Calipso (white dots). The orography is indicated by the strong surface backscattering signal (dark red line). The CloudSat overpass was from south-west to north-east across Germany. Middle panel: PAMTRA simulation for the same track as CloudSat based on the reanalysis without LHN. Lower panel: Same as middle panel but with operational LHN. Note that for the PAMTRA simulations only frozen hydrometeors have been considered and that CloudSat observations (footprint 1.2 km) are not averaged onto the COSMO-DE grid (2.8 km).**

The relatively thin ice clouds in the north-easterly part of Germany (see also the satellite image in Figure 1) only produce a weak TB depression while several thunderstorm systems can be identified containing large amounts of frozen hydrometeors and thus producing significantly lower TB. A comparison of the cases with LHN turned on and off reveals that the LHN triggers convective cells containing very large amounts of frozen hydrometeors. Overall, the cloud field becomes more fractioned with LHN. The passive microwave observations are thus an important complement to the MSG observations in the infrared since they provide information about the ‘thickness’, i.e. the total hydrometeor content of the cloud.

In order to further explore the vertical structure of the cloud system, simulations have also been performed for a 94 GHz cloud radar (Figure 3). The CloudSat and collocated Calipso lidar observations reveal a large-scale precipitation system including intense convection with large hydrometeor contents reaching the tropopause. For the active PAMTRA simulations we concentrated on the areas above the melting layer since the radar signal below the melting layer is significantly more affected by attenuation. Comparing first the simulations with observations, the precipitation system is found to be well captured by the model. The simulated values for radar reflectivity are slightly higher in the model simulations but are still in the range of the observations. As already found in the MSG observations, the overestimation of high ice clouds in the model is evident. The simulations for LHN-on/off reveal the vertical structure of the small-scale plumes that have been identified in Figure 1 and 2. One example of such a plume can be found on the lowest panel (operational LHN) of Figure 3 at latitudes between 51° and 52° and heights between 9 and 13 km. The plume triggered by the LHN scheme rises up to the tropopause carrying significant amounts of frozen hydrometeors. Similar simulations applied to longer time periods and different LHN increments will provide information about the best setting of LHN in order to account for the hydrological cycle as well as cloud structure and their radiative effects.

## 6. CONCLUSIONS AND OUTLOOK

First validation studies using an extensive observational dataset and the recently developed passive and active microwave forward operator PAMTRA revealed the effect of LHN on the precipitation field and on the spatial cloud structure. The studies about the impact of LHN will be extended to longer time periods – reanalysis data for 2007 and 2011 will be available soon - and with focus on the impact of LHN on water and energy cycle. New verification techniques will be developed to make use of the specific information in the observational dataset and to account for dependencies on e.g. weather type regime, cloud type or precipitation system.

## 7. ACKNOWLEDGEMENTS

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